Space Weather Efforts in Boulder: A Brief History

Ernest Hildner

Space Weather Workshop

2015 April 14

Space Weather Research Milestones - 1

1940 - W. O. Roberts builds the Climax Statin of Harvard Observatory (at 10,000 ft elevation) and starts observing near Climax, CO

1948 - CU Physics Dept. forms Upper Atmosphere Lab.

1946 – Climax Station transfers from Harvard to CU, becomes High Altitude Observatory and moves HQ to Boulder

Walter Orr Roberts
Harvard graduate student ca.1941

5-inch coronagraph at Climax Observatory

Space Weather Research Milestones - 2

1956 – CU physicists and Ball Brothers create Ball Research Corp., now Ball Aerospace and Technologies Corp.

1958 – First PhD class in Astro –Geo Department:

1960 – NCAR created, W. O Roberts founding Director, and HAO becomes a part of it, still housed on CU campus

High Altitude Observatory
Left, Summers-Bausch Observatory, 1948
Right, CU's Astro-Geophysics Building, Dedicated 1960

Space Weather Research Milestones - 3

Mid ‘60s – NOAA research into flare probabilities
(McNish-Lincoln; McIntosh Active Region classes)

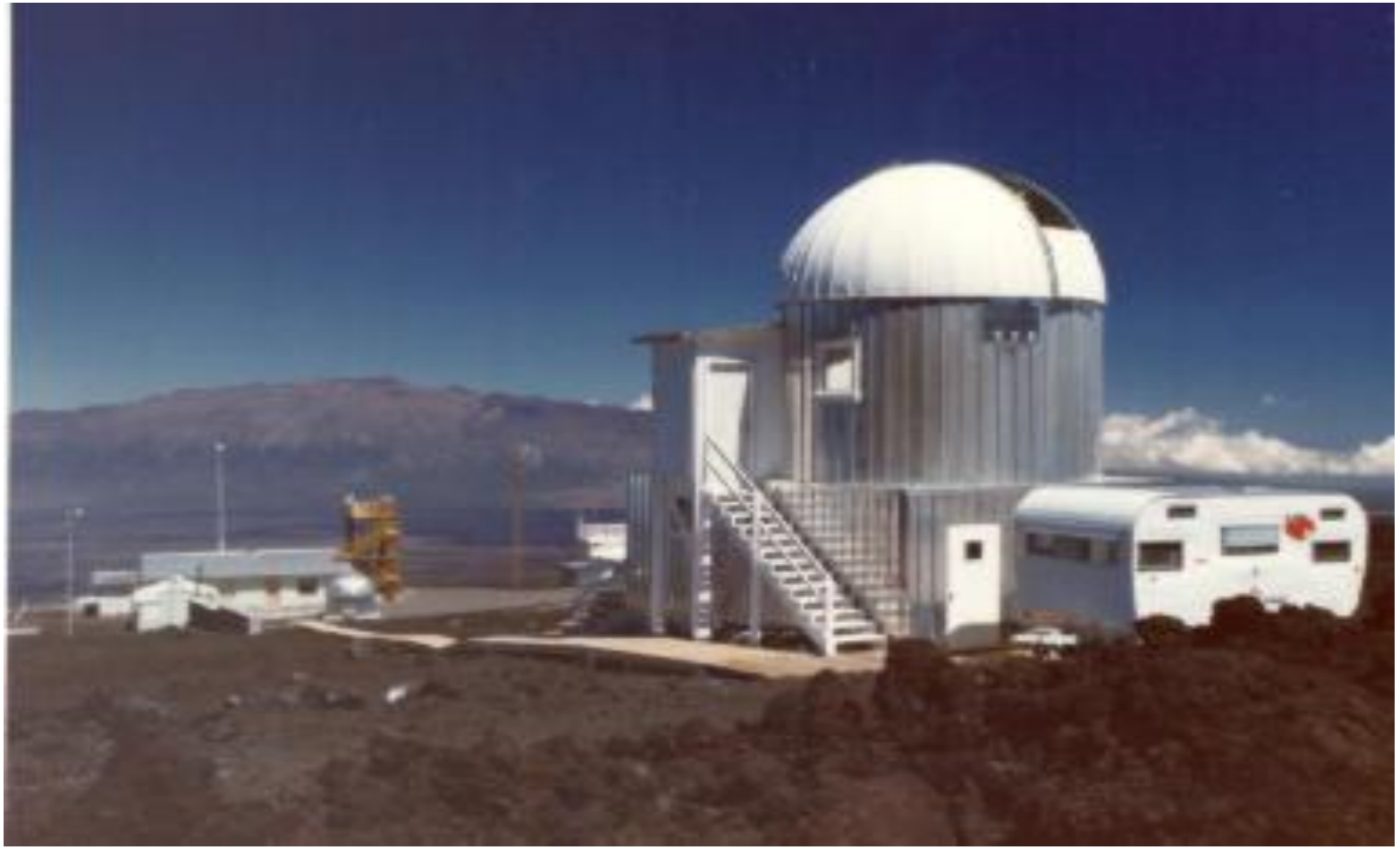
1962 – Joint Inst. for Lab. Astroph. (JILA)* created by CU and NBS
(three of Univ. Colorado’s four Nobel Prizes from JILA)

1965 – Lab. for Atmospheric and Space Physics (LASP)* gets its current name (formerly Upper Atmosphere Lab.)

1965 – HAO establishes Mauna Loa Observatory

* Affiliated with CU’s Department of Astrophysical and Space Physics

Mauna Loa Solar Observatory
1965



Space Weather Research Milestones - 4

1973 – Skylab launched with HAO's coronagraph, built by Ball Aerospace, on board

CORONAGRAPH GROUP BESIDE A MOCKUP OF THE SKYLAB ATM

R. MacQueen (PI) A. Poland E. Hildner H. Avant J. Gosling R. Munro
A. Csoeke-Poeckh ? C. Ross R. Broussard

Space Weather Research Milestones - 5

1878 – Orbiting Solar Observatory – 8 (OSO-8) launched with LASP's High-Resolution UV Spectrometer aboard

1985 – Center for Astrophys. and Space Astronomy (CASA) created
Affiliated with CU's Department of Astrophysical and Space Science

Space Weather Research Milestones - 6

1994 – Outpost of Southwest Research Institute (SwRI) arrives

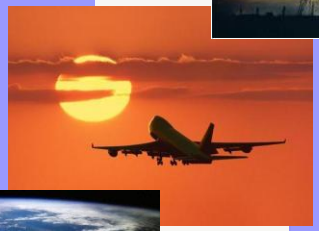
1997–Colorado Research Associates(CoRA) forms, now part of North West Research Associates (NWRA)

2006 – Boulder Solar Alliance forms. Current members:

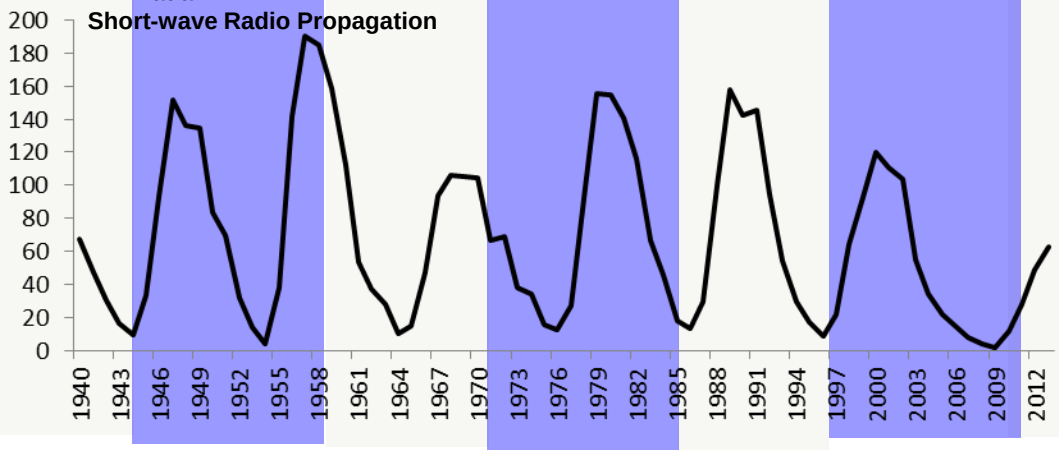
LASP HAO SWPC NGDC JILA CORA SwRI NSO

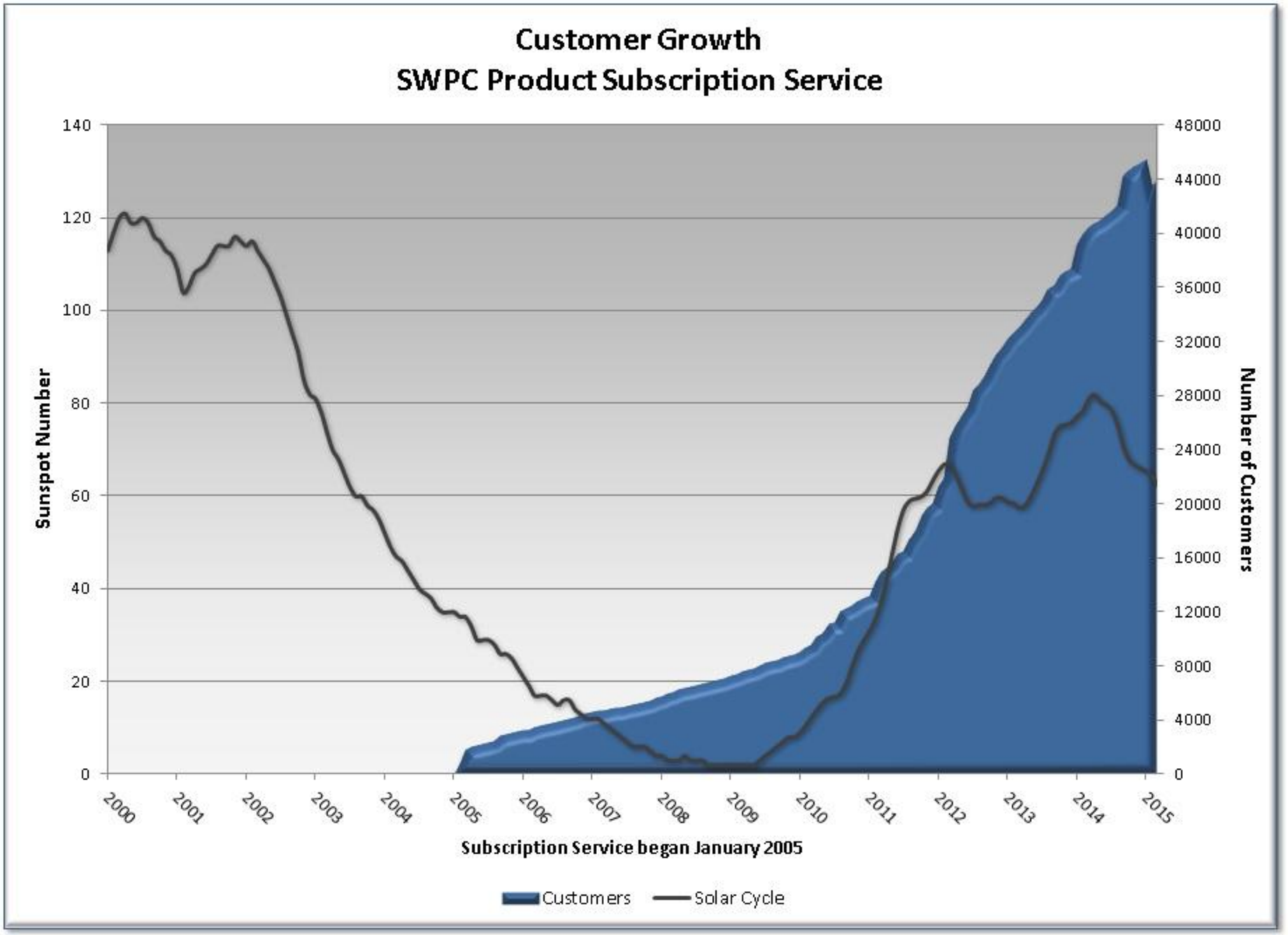
2016 – National Solar Observatory (NSO) completes its move to Boulder!

Growth of Space Weather Customers



Precision Agriculture
Unmanned Aerial Vehicle
Commercial Space Transportation
Airline Polar Flights
Oil drilling
Microchip technology
Precision Guided Munitions
Cell phones
GPS Navigation
Ozone Measurements
Aircraft Radiation Hazard
Commercial TV Relays
Communications Satellite Orientation
Spacecraft Charging
Satellite Reconnaissance & Remote Sensing Instrument Damage
Geophysical Exploration.
Pipeline Operations
Anti-Submarine Detection
Satellite Power Arrays
Power Distribution
Long-Range Telephone Systems
Radiation Hazards to Astronauts
Interplanetary Satellite experiments
VLF Navigation Systems (OMEGA, LORAN)
Over the Horizon Radar
Solar-Terres. Research & Applic. Satellites
Research & Operations Requirements
Satellite Orbit Prediction
Solar Balloon & Rocket experiments
Ionospheric Rocket experiments
Radar
Short-wave Radio Propagation




Customer Growth
SWPC Product Subscription Service
Sunspot Number
Number of Customers
140
120
100
80
60
40
20
0
48000
44000
40000
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Subscription Service began January 2005
Customers
Solar Cycle

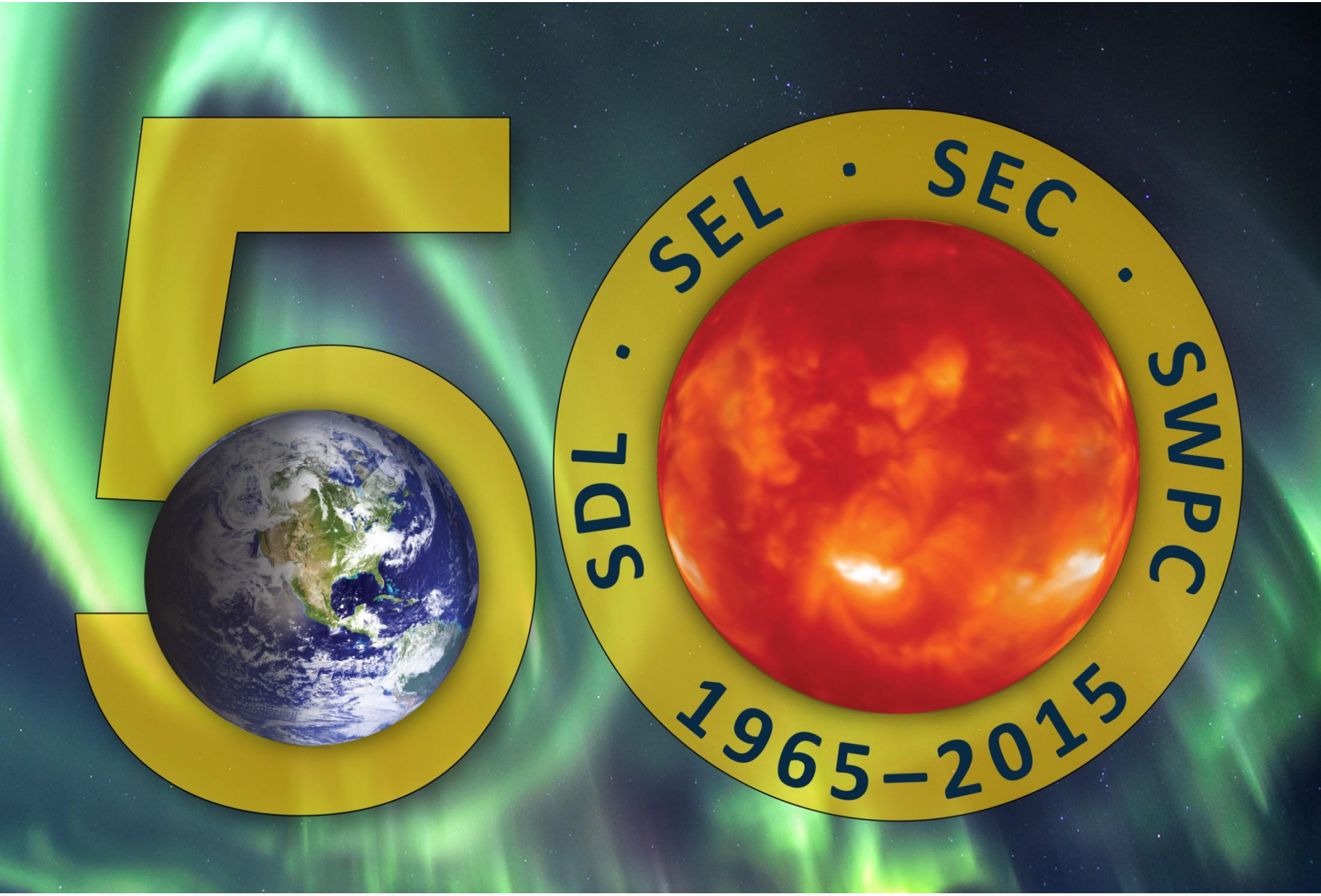
Space Weather Operations Milestones - 1

1946 – Central Radio Propagation Lab. (CRPL) comes to Boulder

1954 – NBS Radio Building dedicated, includes CRPL, which includes Space Disturbances Laboratory (SDL). NBS comes to Boulder in large part because W. O. Roberts was good friend of NBS Director, E.U. Condon

1965 – CRPL is part of newly formed Environmental Science and Services Administration (ESSA)

1965 – Space Disturbances Laboratory starts daily space weather forecasts to the public!


50
SDL · SEL · SEC · SWPC
1965–2015

How Space Weather Ops Were Done

(Thanks to Joe Hirman for information)

1944-45 - During WW II, radio and radar operators used their “gut feel”, based on the general level of solar activity

~1945-1960 - Central Radio Propagation Laboratory issued monthly predictions for HF radio based on solar activity trends

1957 - Particles became interesting (after Sputnik). Intensity and speed of radio bursts statistically associated with protons. Observatories sent a teletype message to Boulder and USAF, producing a punched paper tape. Fed into a decoder, the radio burst profile emerged, intelligible to humans.

How Space Weather Ops Were Done

H-alpha flare intensities and locations also correlated with particle events at Earth.

- Obs every 2 minutes. Coded messages to Boulder and USAF.
- Flares photographed, film developed, print scanned by Wirefoto machine, transmitted shades of grey via analog voice telephone line to NOAA, to modulate a light beams on film, film developed .

The resulting low-quality image had, at least, an hour's latency

These radio burst profile and H-alpha image techniques were the best that could be done all the way up to Skylab in 1973.

How Space Weather Ops Were Done

1968 - Navy's SOLRAD provides X-ray brightness of flares, leading to the C, M, and X classification of flares

1960s- McIntosh Active Region classes from H-alpha photos used to make next-day flare forecasts

1974 – NOAA satellites begin to measure magnetic field at geo-synchronous orbit

19XX – NOAA weather satellites begin to carry X-ray detectors, and forecasters could actually see a flare develop in realtime. **This allowed, for the first time, quantitative verification of forecasts.** X-rays used to forecast the next few minutes, H-alpha still used to predict tomorrow's flare probabilities.

How Space Weather Ops Were Done

1960s-70s – NOAA weather satellites begin to carry particle detectors

1994 – WIND data available in realtime at SWPC for one-hour forecasts of geomagnetic storms. With WIND, NASA begins its continuing policy of making space weather research data available to SWPC in realtime

2001 – NOAA weather satellites begin to carry Solar X-Ray Imagers

Space Weather Operations Milestones - 2

1968 – Space Disturbances Laboratory starts 24x7 operations

1970 – ESSA, plus others, morphs into National Oceanic and Atmospheric Administration (NOAA), SDL becomes Space Environment Laboratory (?)

Mid ‘70s – Try to predict the next solar cycle

Forecasting Four Solar Cycles

1969 – NASA's prediction for Skylab reentry was badly wrong. Every operator of orbiting spacecraft wishes to know the profile of the current and next solar cycle, to forecast drag.

Mid '70s – NASA convened a panel to issue "the official" prediction for Solar Cycle 21

Again, for Cycles 22 – 24, NASA has funded a panel, chaired by NOAA, to make "the official" prediction. The existence of these panels and the interactions among panel members has stimulated research into understanding – and predicting – the course of future solar cycles.

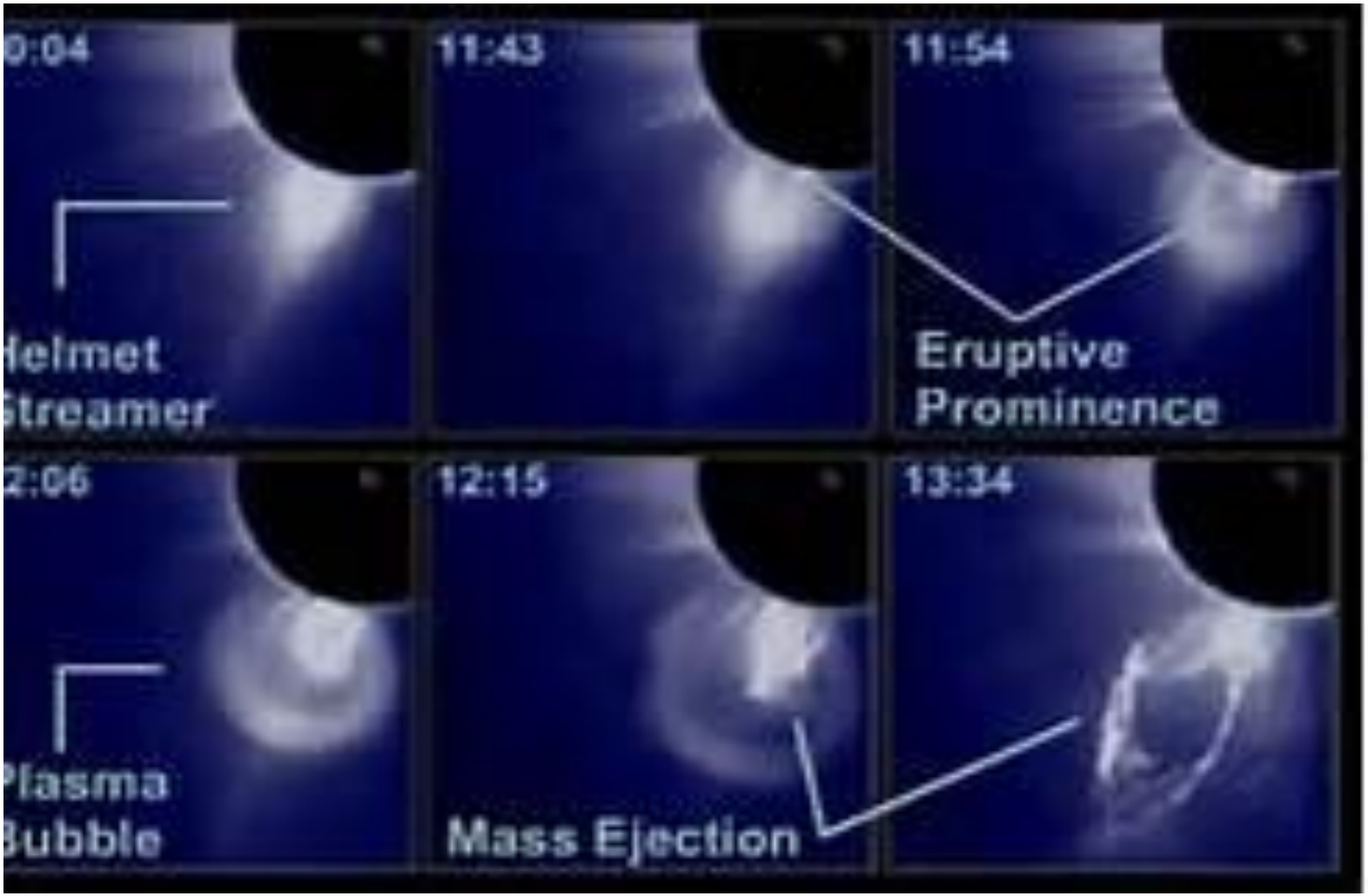
Space Weather Operations Milestones – 3

1973 – Space Environment Laboratory operates two forecast centers, in Boulder and at Johnson Space Center

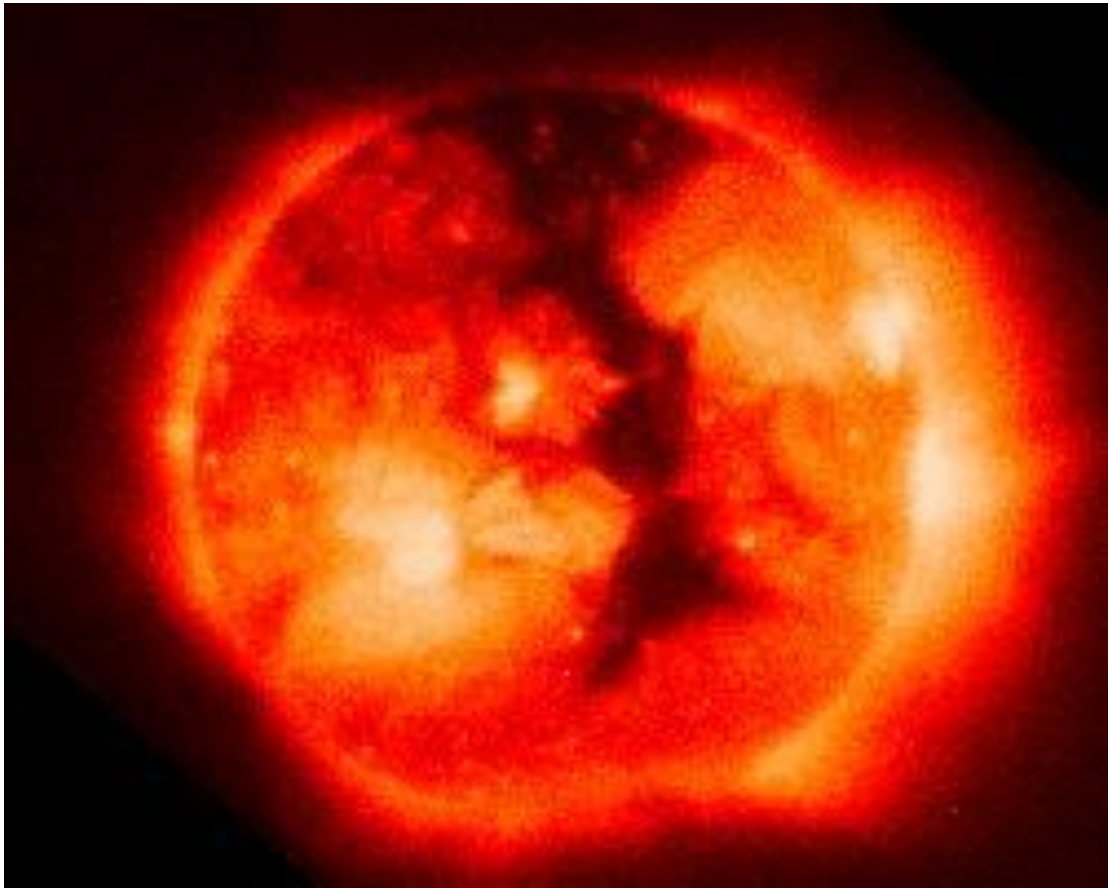
1978 – NOAA's TIROS-N weather satellite carries a proton monitor, added to the electron monitor carried by earlier TIROS

Late '70s – Results pour in from Skylab observations, which affect forecasts

Coronal Mass Ejections
the sources of major geomag storms



Coronal holes explain recurrent geomagnetic storms



Space Weather Operations Milestones - 4

1980s- Computers proliferate, networks are realized (DARPANET, NSFNet, Internet, then WWWeb) and gradually replace the old Teletype and punched-paper tape data handling for incoming data and outgoing products

1995 – SEL becomes affiliated with National Weather Service and is renamed Space Environment Center (SEC)

1998 – Space Weather Ops move to the current location in NOAA's David Skaggs Building after its dedication

1999 – Space Weather Week annual meetings begin

16TH Annual Meeting, almost one-third of the 50 Years being celebrated in 2015

Space Weather Operations Milestones - 5

~2000- Global Oscillation Network (GONG) provides info on magnetic regions on far side of Sun

2005 – Space Environment Center (SEC) shifts from NOAA Research to National Weather Service, National Centers for Environmental Prediction (NCEP)

Space Weather Operations Milestones - 6

2006 – STEREOs launch, eventually showing Earthward CMEs, providing a day or so advanced warning before hitting Earth

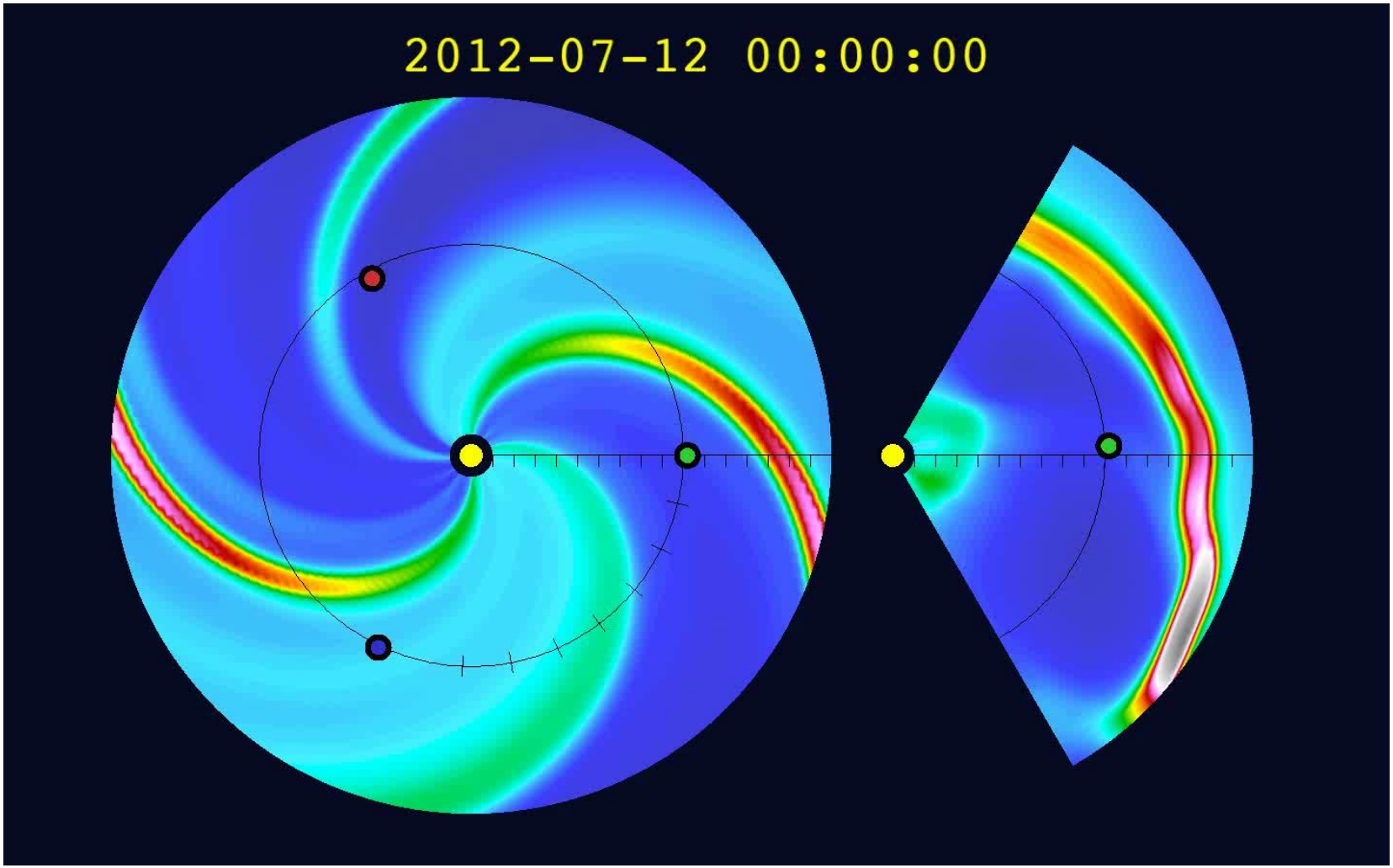
2007 – SEC becomes Space Weather Prediction Center (SWPC)

2011 – First numerical model in ops, WSA–Enlil

2015 – Deep Space Climate Observer (DSCOVR) mission to L1 - Launch Feb 25; solar wind data from L1 ~ June

Left, The ecliptic showing Earth and two STEREO spacecraft

Right, The meridional plane through Earth's location



G. Millward

Further reading

A book on the history and development of space weather:

Sentinels of the Sun – B. Poppe and K. Jorden, 2006

Amazon has only one copy, paperback, listed for $134.50 !!, so look in your local library.